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NATURAL AND ANTHROPOGENIC FACTORS IN THE FORMATION OF THE FLOW OF PLAIN RIVERS OF KAZAKHSTAN IN THE CONDITIONS OF NON-STATIONARY CLIMATE

The change in the flow of plain rivers in Kazakhstan in recent decades is done due to the influence of both climatic factors and anthropogenic impacts. Revealing their role is extremely important for understanding the genesis of hydrological changes that have already occurred and possible in the future, as well as for taking measures to reduce their undesirable consequences. The complexity of solving this problem lies in the fact that climatic and anthropogenic changes in river runoff are closely interrelated and often interact on the runoff not directly, but indirectly. The intensity of anthropogenic impact, the variability of climate characteristics determine changes in the hydrological regime of water bodies. Climatic variability leads to an increase in the likelihood of adverse hydrometeorological phenomena, and human economic activity in the watershed and in the riverbed leads to a quantitative and qualitative change in the main characteristics of the hydrological regime, degradation of river ecosystems. The changes in the annual runoff of plain rivers are estimated based on the method based on the restoration of the natural runoff of the last decades, during which significant anthropogenic changes took place. It is shown that climatic and anthropogenic factors act on the runoff both unidirectionally, increasing or decreasing it, and in opposite directions. At the same time, the influence of anthropogenic factors, mainly reservoirs and water consumption, is commensurate with the influence of climatic factors, and in many cases exceeds it.

Key words: river runoff, base period, long-term runoff fluctuations, anthropogenic factors, climatic factors.

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Өзгермелі климат жағдайында Қазақстан өзендері ағындысын қалыптастырушы табиғи және антропогендік факторлар

Қазақстанның жазықтық өзендері ағындысының соңғы жылдардағы өзгерісі климаттық және антропогендік факторлармен айқындалады. Қазіргі және болашақта байқалуы мүмкін гидрологиялық өзгерістердің себебін түсіну және осы өзгерістердің әсерінен туындайтын қолайсыз зардаптарды жеңілдету бойынша шаралар қабылдау үшін олардың рөлін айқындау өте маңызды. Өзен ағындысының климаттық және антропогендік өзгерісі өзара тығыз байланысты болғандықтан және көп жағдайда өзен ағындысына тікелей емес жанама әсер ететіндіктен қойылған міндеттерді шешу өте күрделі. Су нысандарының гидрологиялық режимінің өзгерісі ағындығы әсер ететін антропогендік факторлардың қарқындылығы және климаттық сипаттамалардың құбылмалылығымен айқындалады. Климаттың өзгергіштігі қолайсыз гидрометеорологиялық құбылыстардың қайталану жиілігін арттырады, ал су жинау алаптары мен өзен арналарында жүргізілетін адамның шаруашылық іс-әрекеті өзендердің негізгі гидрологиялық сипаттамаларының сандық және сапалық өзгерісіне, өзен экожүйесінің бұзылуына алып келеді. Зерттеу тақырыбының өзектілігі өзендерден алынатын су көлемінің артуына, суды тұтыну көлемінің ұлғаюына және климаттың қолайсыз өзгерістеріне байланысты су ресурстары жетіспеушілігімен анықталады. Жазықтық өзендердің жылдық ағындысының өзгерісі соңғы онжылдықтар ішінде айтарлықтай антропогендік өзгеріске ұшыраған табиғи ағындыны қалпына келтіру әдісі арқылы бағаланады. Бұл мақсатта су режимі салыстырмалы аз өзгеріске ұшыраған өзендердің (қарастырылып отырған өзендердің салалары мен жоғарғы ағысы) ағындысы жөніндегі деректер пайдаланылды. Қалпына келтірілген ағынды деректері осы кезең аралығында антропогендік өзгеріске ұшыраған ағынды деректерімен және оған дейіңгі антропогендік әсерді ескермеуге болатын негізгі кезең ағындысымен салыстырылды. Климаттық және антропогендік факторлар өзен ағындысын бір бағытта ұлғайтатыны немесе азайтатыны, сондай-ақ қарама-қарсы бағытта әсер ететіні көрсетілген. Оның үстіне антропогендік факторлардың негізінен бөгендер мен су тұтынудың ағындыға тигізетін ықпалы климаттық факторлардың ықпалымен шамалас және көп жағдайда одан асып түседі.

Түйін сөздер: өзен ағындысы, негізгі кезең, ағындының көпжылдық тербелісі, антропогендік факторлар, климаттық факторлар.

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Природные и антропогенные факторы в формировании стока равнинных рек Казахстана в условиях нестационарности климата

Изменение стока равнинных рек Казахстана в последние десятилетия обусловлено влиянием, как климатических факторов, так и антропогенных воздействий. Выявить их роль чрезвычайно важно для понимания генезиса уже произошедших и возможных в будущем гидрологических изменений, а также для принятия мер по снижению их нежелательных последствий. Сложность решения этой задачи заключается в том, что климатические и антропогенные изменения речного стока тесно взаимосвязаны и часто взаимодействуют на сток не непосредственно, а косвенно. Интенсивность антропогенного воздействия, вариабельность характеристик климата определяют изменения гидрологического режима водных объектов. Климатическая изменчивость приводит к увеличению вероятности неблагоприятных гидрометеорологических явлений, а хозяйственная деятельность человека на водосборе и в русле реки приводит к количественному и качественному изменению основных характеристик гидрологического режима, деградации речных экосистем. Актуальность темы исследований определяется нарастающим дефицитом водных ресурсов в связи с увеличением изъятия объемов воды из рек, увеличением объемов водопотребления и неблагоприятными климатическими тенденциями. Оценены изменения годового стока равнинных рек на основе метода, основанного на восстановлении естественного стока последних десятилетий, в течение которых происходили его существенные антропогенные изменения. Для этих целей использованы данные о стоке рек (притоков рассматриваемых рек и их верхних частей), водный режим которых относительно слабо изменен антропогенным воздействием. Данные о восстановленном речном стоке сравнивались с антропогенно-измененным стоком за этот период и за предшествующий ему базовый период, когда антропогенным воздействием можно пренебречь. Показано, что климатические и антропогенные факторы действуют на сток как однонаправленно, увеличивая или уменьшая его, так и в противоположных направлениях. При этом влияние антропогенных факторов, главным образом водохранилищ и водопотребления, соизмеримо с влиянием климатических факторов, а во многих случаях превосходит его.

Ключевые слова: речной сток, базовый период, многолетние колебания стока, антропогенные факторы, климатические факторы.

Introduction

Significant changes in climatic conditions and the rapid transformation of the economic complex in recent decades have led to negative changes in river flow. In the basins of lowland rivers in Kazakhstan, over the past few decades there has been a marked warming of the climate, which is accompanied by an expand in air temperature and, to a lesser degree, in atmospheric moisture. These changes are characterized by considerable spatial heterogeneity and lead to multidirectional changes in flow. They are superimposed on changes caused by a wide range of anthropogenic influences, both in river channels and in their watersheds. At the same time, the ratio of the contribution of natural-climatic and anthropogenic factors in the occurring and scenario changes in the flow remains insufficiently studied, despite the studies conducted by scientists-hydrologists.

The territory of Kazakhstan is characterized by uneven distribution of water resources in space and time, the possibility of using water resources has reached such a size that the flow deficit has become a limiting factor for socio-economic growth of the area. At present, major water problems are clearly observed in the river basins, which in a few years may become a factor hindering the socio-economic development of the region. Therefore, it is necessary to take urgent measures taking into account long-term nature of water projects development and implementation.

The flow of the lowland rivers of Kazakhstan is characterized by long-term changes that are caused by natural-climatic and anthropogenic factors. A large number of scientific studies have been devoted to the dynamics of long-term changes in river flow and the role of individual factors of such changes (Galperin et al., 2012; Shiklomanov, 2008; Koronkevich et al., 2003; Shiklomanov, 1989; Shiklomanov, 1979). While identifying separately the contribution of climatic and anthropogenic factors to these changes remains one of the urgent problems. First of all, the issue is the difficulty of separating their influence on river flow, since natural and anthropogenic factors act simultaneously and are closely interrelated. Various studies and assessments of the contribution of factors are often timed to different time periods and there remain periods not covered by scientific research (Dostay et al., 2012; Abishev et al., 2016; Georgiadi et al., 2014; Georgiadi et al., 2009; Koronkevich, 1990).

The list of anthropogenic factors taken into account significantly differs, and indirect anthropogenic influences on runoff are rarely taken into account. Different methods are used in studies to identify the hydrological role of climatic and anthropogenic factors and to assess the ratio of these factors in hydrological changes (Alimkulov et al., 2018; Koronkevich et al., 2015; Andreyanov, 1959; Kuzin, 1970; Alimkulov et al., 2021; Georgiadi et al., 2012; Georgiadi et al., 2014; Moldakhmetov et al., 2014; Moldakhmetov et al., 2020; Georgiadi et al., 2017).

According to Sustainable Development Goal 6, “Ensure availability and sustainable use of water resources and sanitation for all,” by 2030 it is necessary to significantly improve the efficiency of water use in all sectors of the economy (ensuring sustainable freshwater abstraction and supply to address scarcity) and ensure integrated water resources management at all levels. Under the Goal 13 “Take urgent action to combat climate change and its effects” requires the inclusion of responses to climate change in policies, strategies and planning at the national level and the adoption of meaningful measures to mitigate the effects of climate change (World Sustainable Development Report, 2020).

In the late XX and early XXI centuries, the accomplished fact of global warming was acknowledged (Galperin et al., 2012; Shiklomanov, 2008; Koronkevich et al., 2003; Shiklomanov, 1989; Modern global changes in the natural environment, 2006; Georgievsky, 1996), but the debate about the causes of contemporary climate change remains incomplete. Many scientists acknowledge the fact of anthropogenic climate change due to carbon dioxide accumulation in the atmosphere, while others firmly believe that the energy power of the processes taking place in the natural cycle is some orders of magnitude higher than the technogenic energy capabilities. Rhythms of space, natural rhythmicity and its phases have a significant influence on many processes occurring on the Earth, including long-term fluctuations of river runoff, which is an integral indicator of climate change (Ineson et al., 2015; Gray et al., 2010).

The problem of global climate change and its forecast is now given great attention in the world; this problem is reflected, in particular, in the following scientific works (Makhmudova et al., 2021; Frolova et al., 2013; Meleshko, 2008). According to scientific research given in (Meleshko, 2008) it follows that at least since the beginning of XX century the global problem has been growing – according to smoothed values by 0.75 ^{0}C. After a temporary cooling from the mid-1940s to the mid-1960s, there was already a continuous rise in temperature, but, it is very indicative, an exceptionally powerful warming since the mid-1970s. This phenomenon was noted much earlier – so, O.A. Drozdov (Drozdov, 1992) pointed out that a new warming in the world began in 1973 and, on this basis, doubt was expressed about the possibility of predicting future water resources on the basis of long series of observations. According to V.P. Meleshko’s research (Meleshko, 2008) the probability of warming since the mid-20th century is related to the concentration of greenhouse gases more than 90 %, it follows that warming will continue (Makhmudova et al., 2021).

As for anthropogenic changes in runoff of the last modern period, they are quite reasonably disturbing for humanity. These changes really exist, but their values are not comparable with natural cyclical climate changes of different nature. The danger of anthropogenic changes lies in their irreversibility. Besides, a combination of accumulating anthropogenic and cyclic natural climate changes is dangerous because there are periods of years when anthropogenic and natural changes are directed in the same direction and can manifest with threatening rapidity, so minimizing the anthropogenic component is a safety net for mankind.

For a reliable integrated assessment of water resources and water availability in the basin or region for the present and future, in addition to data on fluctuations in river flow, it is necessary to quantify its changes under the influence of climatic and anthropogenic factors.

According to the research of the following authors (Alimkulov et al., 2018) since the one thousand nine hundred seventy, the relevance of dependable assessment of water resources and their projected changes below the influence of economic action has increased even more in connection with the genuine problem of changes in global and regional climatic characteristics. These changes are already taking space in the plain rivers of Kazakhstan and can lead to large-scale transformations of the hydrological cycle, changes in water resources and their use, distribution in time and space, extreme characteristics of river flow and their variability.

Scientific studies (Meleshko, 2008) contain the following statement, in the distribution of water resources in the future: in areas of excessive moisture water resources will increase, and in areas where water availability is now insufficient, its further reduction is foreseen. Apparently, such feature of water resources dynamics is typical for Kazakhstan as well. Indeed, in the inland areas of middle latitudes, increasing temperature causes an increase in evaporation, reducing the period of snow accumulation (Makhmudova et al., 2021; Moldakhmetov et al., 2013), which has a negative impact on river runoff.

Anthropogenic changes in climatic characteristics are so significant that they have led to significant violations of the hydrological cycle, the quantity of water resources, their distribution over time and territory, the extreme characteristics of river flow and their variability, which cannot be ignored when developing long-term integrated use plans when designing long-term water management measures (Alimkulov et al., 2018).

Most of the researches devoted to the study of water resources of Kazakhstan and the regularities of their spatial and temporal changes operate with the values of annual runoff and inter-annual variability (Shults, 1965; Sosedov, 1984; Boldyrev, 1965; Galperin, 1970; Dostaev, 1990). Far fewer works study the maximum and minimum flow, intra-annual regime and other hydrological issues of narrow focus (Boldyrev, 1965; Galperin, 1970; Dostaev, 1990). Meanwhile, the annual values of river runoff consist of water volumes of individual genetically based phases of its formation, during which, in fact, significant responses to climatic and anthropogenic changes are observed.

The first major works that carried out comprehensive hydrological studies, including the water regime and intra-annual flow distribution of rivers in Kazakhstan, were the series of monographs "Surface Water Resources of the USSR", published in 1950-1970. Peculiarities of the regularities of flow formation, distribution, and water regime of individual regions of Kazakhstan were considered in the works of Soviet scientists (Kuzin, 1953; Berkaliev, 1959). The early works of Kazakh scientists such as V.M. Boldyrev, R.I. Galperin, S.K. Davletgaliev, A.A. Tursunov, J.D. Dostay, and others also belong to this group (Boldyrev et al., 1994; Galperin, 1992). It should be noted that in all works of this period, hydrological assessments were carried out from the position of climate stationarity and flow formation processes.

In scientific researches of foreign authors (Hughes et al., 2000; Technical report, 2010; Pekarova et al., 2008; Piniewski et al., 2011), methods and principles of trends accounting, water resources assessment, water regime changes are given. These works are aimed at studying water regime and management developed by methodologies financed by water departments of countries and UNESCO. In recent years, it is possible to note studies of the impact of climate change on river flow in the works of scientists of the Institute of Water Problems of the Russian Academy of Sciences A. Georgiadi, N. Koronkevich, I. Milyukova, A. Kislov, O. Anisimov, E. Barabanova, etc. (Report on research, 2012) on the rivers of the Arctic basin and the Russian plain.

Therefore, the relevance of the topic is determined by the growing scarcity of water resources due to increased withdrawal of water from rivers, unfavourable climatic trends, and increase in water consumption.

The main goal – study of long-term trends in flow changes in the plain river basins under climate variability and anthropogenic load for effective decision-making on water resources management, sustainable development of the region and food security.

Materials and methods

When performing various methods and techniques were used for research work, such as: analytical generalization of known scientific and scientific-technical results; content – analysis; methods of system analysis; statistical methods (analysis of linear trends in multi-year runoff fluctuations; comparison of annual and seasonal runoff values for multi-year periods with the same meteorological characteristics, but with different levels of economic activity development; methods of hydrological analogy; numerous correlations between runoff and meteorological characteristics; analysis of runoff dependencies in catchment areas where it is formed and used for economic needs; territorial multiple dependencies of river runoff on physical-geographical, meteorological and anthropogenic factors); quantitative methods; methods of probability theory and mathematical statistics.

To solve these problems, studies have been conducted based on methods common in hydrology, considering the spatial patterns of changes in river flow, such as a comprehensive physical and geographical analysis, taking into account factors of formation and flow changes, as well as climate modify and anthropogenic influence will be performed.

Hydrological calculations were performed in accordance with the regulatory document SP 33-101-2003 and Methodical Recommendations (Code of Rules, 2004; Rozhdestvensky et al., 2009; Rozhdestvensky et al., 2007; Rozhdestvensky et al., 2010; Standard of the organization, 2017).

The data of RSE (Republican State Enterprise) "Kazhydromet" were used as source materials for the implementation of research works – data from observations on the hydrological and meteorological network of plain rivers of Kazakhstan (average monthly, annual, seasonal flow of the rivers in question, monitoring of meteorological data) for the entire period of instrumental observation.

The research concept is based on an independent approach, in which the integral assessment of the influence of the flow factors under consideration is based on the reconstruction of the conditional-natural annual flow. Using regression relations of annual and seasonal flow of large rivers and their tributaries (river indicators) located in the area of flow formation of the main river under conditions of relatively low anthropogenic impact, and comparison of the restored flow with the actual flow (Georgiadi et al., 2013; Georgiadi et al., 2019). The developed approach gives an opportunity to reveal long-term integral changes of river runoff – assessment of river runoff changes caused by natural-climatic factors (according to relations between runoff of the main-river and river indicators).

For each river in the study basins, the boundaries of base periods, average values of annual and seasonal runoff and their difference are calculated for these periods (the difference will show the total changes in the runoff, which occurred under the influence of both anthropogenic impacts and climatic factors).

To determine the contribution of anthropogenic and climatic factors in the total change of annual and seasonal runoff, the method based on the reconstruction of natural runoff of the studied rivers was applied. The method is founded on regression relations between runoff of large rivers and their tributaries. For this method, assessment of the contribution of anthropogenic impacts and climatic changes in the total runoff changes is based on comparing the runoff for the baseline period, which was relatively weakly affected by economic activities, with the actual and restored (conditionally natural) runoff for the period of significant anthropogenic impact (Georgiadi et al., 2019).

Studies of long-term flow changes are based on the concept of long-term phases of increased or decreased water availability and the influence of anthropogenic factors on them (based on which the contribution of natural-climatic and anthropogenic factors to the observed changes in annual and seasonal flow is estimated) (Georgiadi et al., 2020).

Methodological methods, based mainly on the use of network observations, provide only an integral assessment of the impact of a set of anthropogenic factors in the basin, but do not allow to identify the role of each factor individually and thus do not always provide the possibility of scientifically based forecasts of the river regime in the future, taking into account economic development plans. Therefore, for watersheds with intensive use of water resources, assessment of flow changes should be made in parallel by two mutually independent methods, namely by restoring the conditionally natural annual runoff using regression relationships and by analyzing long-term water discharge fluctuations in gauging stations (with regard for meteorological factors fluctuations). When calculating for the future, it is important to assess runoff changes under the influence of economic activity not only for average water availability, but also for exceptionally low-water and high-water years. In general, the above methods together serve as a methodological basis for achieving the goals of the scientific researches and the chosen scientific approach.

Results and discussion

Choosing a billing period in a changing climate for such a large and complex orographically territory as lowland Kazakhstan is very difficult. Firstly, it's challenging to expect complete consistency of fluctuations in the hydro-climatic characteristics in all basins. Secondly, river flow is affected by economic activity, but it's not the same in different parts of the territory and varies significantly over time. Further, it's quite obvious that the common hydroclimatic patterns should be better manifested in large basins. In nearly all large and medium rivers of flat Kazakhstan, the climatic flow is strongly distorted, in particular, by reservoirs (Makhmudova et al., 2021). When analyzing, one should keep in mind the features of runoff time series in a significant part of Kazakhstan: exceptional, unparalleled, low water in the 1930s, and very high runoff in the 1940s (Galperin et al., 2003). Difference integral curves are widely used to identify the phases of increased and decreased water content of rivers, the moments of change of these phases. But, it should be borne in mind that they illustrate the course of the accumulated anomaly only relative to the sample mean. An analysis of the river runoff dynamics in the region under consideration shows that runoff fluctuations occur cyclically (Table 1), which has been repeatedly noted by most researchers (Galperin et al., 2003; Makhmudova et al., 2021). An analysis of the data for all hydrological series of the territory under consideration reveals one common feature of the long-term course – the increase in runoff values since the mid-1970s regardless of whether this period belongs to the low-water or high-water phase. The moment of transition to the high-water phase corresponds to the data on the long-term variation of global meteorological characteristics (Shiklomanov, 2008; Modern global changes in the natural environment, 2006).

Table 1 – Low-water and high-water periods on plain rivers

Low water periods			High water periods			Cycle duration	Average consumption for the period, m^3/s
Period, years	Cycle, yy.	Average consumption for the period, m^3/s	Period, yy.	Cycle, yy.	Average consumption for the period, m^3/s		
Tobyl – Kostanay							
1931-1939	9	5.85	1940-1943	4	36.4	13	15.2
1944-1945	2	7.46	1946-1953	8	25.9	10	22.2
1954-1956	3	6.93	1957-1964	8	15.5	11	13.1
1965-1969	5	2.09	1970-1973	3	17.6	9	8.46
1974-1984	11	1.94	1985-1986	2	11.1	13	3.35
1987-1989	3	4.57	1990-1994	5	23.4	8	16.3
1995-1996	2	4.23	1997-2005	9	16.1	11	14.0
2006-2011	6	5.58	2012-2019	8	7.26	14	6.54
Yesil – Petropavlovsk							
1933-1939	7	13.9	1940-1949	10	111	17	70.7
1950-1953	4	18.7	1954-1964	11	66.8	15	54.0
1965-1969	5	22.8	1970-1974	5	67.2	10	45.0

Table continuation

Low water periods			**High water periods**			**Cycle duration**	**Average consumption for the period, m³/s**
Period, years	**Cycle, yy.**	**Average consumption for the period, m³/s**	**Period, yy.**	**Cycle, yy.**	**Average consumption for the period, m³/s**		
1975-1982	8	26.5	1983-1997	15	81.9	23	62.7
1998-2001	4	15.5	2002-2007	6	69.6	10	48.0
2008-2013	6	19.5	2014-2019	6	112	12	65.7
Nura – Romanovka							
1933-1937	7	6.11	1940-1943	4	19.7	11	11.1
1944-1947	4	14.1	1948-1950	3	38.1	7	24.4
1951-1953	3	8.58	1954-1955	2	24.5	5	15.0
1956-1957	2	6.74	1958-1962	5	30.4	7	23.6
1963-1970	8	8.80	1971-1973	3	28.3	11	14.1
1974-1977	4	13.5	1978-1979	2	22.6	6	16.6
1980-1982	3	13.2	1983-1993	11	34.2	14	29.7
1994-2001	8	13.6	2002-2004	3	29.1	11	17.8
2005-2014	10	11.4	2015-2019	5	65.7	15	30.0
Sarysu – №189							
1932-1939	8	0.64	1940-1945	6	3.77	14	1.98
1946-1947	2	0.28	1948-1949	2	8.18	4	4.23
1950-1953	4	0.69	1954-1955	2	8.91	6	3.43
1956-1957	2	0.31	1958-1960	3	5.90	5	3.66
1961-1963	3	0.52	1964-1966	3	3.36	6	1.94
1967-1968	2	0.14	1969-1973	5	4.61	7	3.33
1974-1975	2	0.47	1976-1977	2	3.30	4	1.89
1978-1979	2	1.29	1980-1992	13	3.82	15	3.48
1993-2001	9	1.84	2002-2006	5	2.91	14	2.22
2007-2014	8	0.78	2015-2019	5	12.0	13	5.10

At the hydrological post Tobyl – Kostanay city over the period of instrumental observations, two complete cycles were identified (1940-1989 and 1990-2019 yy.). High-water phases lasting from 2 to 9 years are replaced by low-water phases lasting from 2 to 11 years, the duration of cycles is from 8 to 14 years. The lowest average annual water discharges in Kostanay were observed in 1979 (0.93 m^3/s) and in 1977 (1.02 m^3/s). The highest average annual water discharges were observed in 1942 (64.5 m^3/s), in 1947 (63.0 m^3/s), and in 1941 (58.2 m^3/s).

In the closing section at the hydrological post of the river Yesil – Petropavlovsk over the period of instrumental observations revealed two complete cycles (1940-1982 and 1983-2013 yy.). High-water phases lasting 5-15 years are replaced by low-water phases lasting from 4 to 8 years, the duration of cycles is from 10 to 23 years. The lowest average annual water discharges in Petropavlovsk were observed in 1968 (1.38 m^3/s) and in 1977 (7.26 m^3/s). The highest average annual water discharges were observed in 1948 (227 m^3/s), in

1941 (175 m^3/s), in 2007 (139 m^3/s) and in 1990 (127 m^3/s).

In the closing section at the hydrological post of the river Nura – Romanovka over the period of instrumental observations revealed two complete cycles (1940-1982 and 1983-2014 yy.). High-water phases lasting 2-11 years are replaced by low-water phases lasting from 2 to 10 years, the duration of cycles is from 5 to 15 years. The lowest average annual water consumption in the village Romanovka were observed in 1939 (1.44 m^3/s) and in 1936 (1.52 m^3/s). The highest average annual water discharges were observed in 1993 (63.6 m^3/s), 1990 (62.4 m^3/s), 1949 (54.6 m^3/s), and 1948 (51.6 m^3/s).

At the hydrological post Sarysu – № 189 over the period of instrumental observations, two complete cycles were revealed (1940-1979 and 1980-2014 yy.). High-water phases lasting from 2 to 13 years are replaced by low-water phases lasting from 2 to 9 years, the duration of cycles is from 4 to 15 years. The lowest average annual water discharges were observed in 1937 (0.010 m^3/s) and in 1947 (0.092 m^3/s). The highest average annual water discharges were observed in 2015 (29.3 m^3/s), in 2017 (15.4 m^3/s), and in 1949 (11.9 m^3/s).

Atmospheric circulation processes have a decisive influence on the distribution of the cyclic phases of climate elements and the hydrological regime over the territory. In addition, the conditions of the underlying surface also play a significant role in this distribution, particularly in relation to the cyclic phases of precipitation and river runoff. The revealed runoff cyclicity can be associated both with the regulating capacity of watersheds and with other factors (peculiarities of atmospheric circulation, etc.). A reflection of climatic variability can also be a modify in runoff variation over time. Water cycles are understood as a series of adjacent runoff years, including one low-water and one high-water grouping of years of the same order of duration. Changes in water content in these periods are due to the predominance of certain types of atmospheric circulations.

The concept of the study makes it possible to identify long-term integral changes in river runoff – an assessment of the modify in river runoff due to natural and climatic factors (by relationships between the flow of the main river and the flow of indicator-rivers). At the same time, as it can be seen, the boundaries of the periods differ on the rivers (Table 2) under consideration, which is explained by the time of the onset of a significant anthropogenic impact (Galperin et al., 2012; Makhmudova et al., 2021; Meshyk et al., 2022; Georgiadi et al., 2020).

Table 2 – Change in the volume of annual runoff under the total impact influence of climatic and anthropogenic factors, relative to the base period

River – point	**Base period**		**Period of significant anthropogenic impact**		**Flow change**		
	years	**runoff volume, million m³**	**years**	**runoff volume, million m³**	**average for the year**		**total, million m³**
					million m³	**%**	
Tobyl – Kostanay	1931-1963	523	1964-2019	293	-230	-44.0	-12880
Yesil – Astana	1933-1970	183	1971-2019	129	-54.0	-29.5	-2646
Yesil – Kamennyi Karier	1933-1970	1302	1971-2019	1211	-91.0	-6.99	-4459
Yesil – Petropavlovsk	1932-1970	1772	1971-2019	1930	158	8.92	7742
Nura – Balykty	1935-1973	189	1974-2019	325	136	72.0	6256
Nura – Romanovka	1933-1973	529	1974-2019	636	107	20.2	4922
Sarysu – №189	1932-1965	84.7	1966-2019	80.7	-4.00	-4.72	-216

Changes in the annual runoff on the rivers that is under consideration (Table 2) had a multidirectional character – the total runoff on the Tobyl River during the period of significant anthropogenic impact decreased, and on the Nura River it increased due to the transfer of runoff from the Ertis – Karaganda canal. At the same time, the runoff of Tobyl near the city of Kostanay changed most noticeably in 1964-2019 decreased in comparison with the base period by more than 12800 million m^3 (over

200 million m^3/year), on the river Yesil in the alignment of Astana for the period from 1971-2019 the decrease in annual runoff amounted to more than 2600 million m^3 (about 50 million m^3/year), on the river Sarysu decline in annual runoff over the period from 1966-2019 amounted to more than 200 million m^3 (5 million m^3/year), which had a very negative impact on the water management and hydro ecological situation in the basins.

When restoring the conditionally natural runoff, it's taken into account: long-term data relating to the period before the onset of a noticeable impact of anthropogenic factors; the second part consists of a long-term series, the annual runoff in which is changed to varying degrees as a result of the anthropogenic factors impact (Georgiadi et al., 2019). The annual runoff was restored by two methods. One of them proceeds from regression relationships between the runoff of the main river and the runoff of rivers that are indicators of climatic conditions (tributaries and upper parts of the main river), characterized by relatively feeble anthropogenic disturbances of the water regime. One of the first to use it was I.A. Shiklomanov (Shiklomanov, 1989; Shiklomanov, 1979). In the Table 3 shows the results of assessing the contribution of climatic and anthropogenic factors to these changes, calculated using the restoring conditionally natural flow method.

Table 3 – Changes in annual runoff over the period of significant anthropogenic impact, calculated by the restoring its conditionally natural values method, million m^3

River – point	Anthropogenic changes		Climate change	
	total for the period	average for the year	total for the period	average for the year
Tobyl – Kostanay	– 10416	– 186	– 2464	– 44
Yesil – Petropavlovsk	– 13328	– 272	21070	430
Nura – Balykty	3404	74.0	2852	62.0
Nura – Romanovka	– 5566	-121	10488	228
Sarysu – №189	– 1528	-28.3	1312	24.3

As follows from Table 3, anthropogenic and climatic changes in the annual runoff on the river Tobyl were unidirectional – downward, and the share of anthropogenic changes is more than 80 %, respectively, the share of climate change is 20 %. On the rivers Yesil, Nura, Sarysu, the effect of anthropogenic and climatic factors was multidirectional with the predominant influence of anthropogenic factors. On the river Nura, the share of anthropogenic changes in the upper reaches is more than 54 %, respectively, the share of climate changes is 46 %, in the lower reaches 87 and 13 %, respectively.

Conclusion

The conducted scientific research is devoted to the complex problem of assessing the role of natural and anthropogenic factors in the formation of the flow of plain rivers. The main emphasis in solving these studies was placed on the problems of non-stationary climate and the uncertainty of hydrological phenomena. The results of scientific research have shown that there is every reason to believe that a certain phase of climate and runoff, which characterizes the current period, began in the 60-70s. XX century, the intensification of economic activity in Kazakhstan also occurred during this period. From the 70s in the XX century, a new phase began in the changes in the water resources of vast territories, with some slowing down of the process or even grouping of years of the opposite sign of the anomaly from the end of the 90s do not give grounds to believe that this phase has ended and been replaced by a new one, these are just random groupings against the backdrop of an established trend. The modern period in the long-term course of the water content of the rivers of the territory under consideration can be considered the period from the mid-70s to the last century. For the rivers of the river basin Tobyl is characterized by runoff cyclicity from 8 to 14 years, for the river Yesil is characterized by a cyclic flow with a period of 10-23 years, for the basin of the river Nura from 5 to 15 years and for the rivers of the river basin Sarysu is characterized by runoff cycles from 4 to 15 years.

The obtained estimates of changes in the volume of annual runoff under the influence of the climatic and anthropogenic factors total impact of relative to the base period showed the following:

– Tobyl – the decrease in runoff is more than 40 %;

– Yesil in the alignment of Astana, the decrease leaves 30 %, further downstream in the alignment with Kamennyi Karier – 7 %;

– Nura – increase in runoff due to the transfer of runoff from the Ertis – Karaganda canal;

– Sarysu – the decrease in runoff is 5 %.

An assessment of the anthropogenic and climatic factors contribution to changes in annual runoff observed river basins: Tobyl, Yesil, Nura, Sarysu, showed the following picture – the share of anthropogenic and climatic factors in the decrease in annual runoff when using the method of restoring conditionally natural runoff is estimated on the river Tobyl in 80 % and 20 %; on the river Yesil 70 % and 30 %; on the river Nura 87 % and 13 % respectively.

The practical significance of the research results lies in the following: the identified long-term and seasonal patterns of the main hydrological characteristics of the plain rivers of Kazakhstan will make it possible to plan and adjust economic activities in the watersheds of the rivers under consideration in conditions of climate variability. The results obtained are necessary as recommendations on the current volumes of rational water use and water consumption in the context of climate change and the impact of human economic activity, in order to change the irrigated areas and plans for the development of the agro-industrial complex.

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